



TITLE:

# The effects of expansion of private wells on rural livelihood in tank intensive watersheds: a case study in upper Gundar River Basin, Tamil Nadu

AUTHOR(S):

SATO, Takahiro; DURAIYAPPAN, Periyar Ramasamy

---

CITATION:

SATO, Takahiro ...[et al]. The effects of expansion of private wells on rural livelihood in tank intensive watersheds: a case study in upper Gundar River Basin, Tamil Nadu. 東南アジア研究 2011, 49(1): 124-150

ISSUE DATE:

2011-06-30

URL:

<http://hdl.handle.net/2433/151871>

RIGHT:

## The Effects of Expansion of Private Wells on Rural Livelihood in Tank Intensive Watersheds: A Case Study in Upper Gundar River Basin, Tamil Nadu

SATO Takahiro\* and Periyar Ramasamy DURAIYAPPAN\*\*

### Abstract

This article aims to investigate the effects of the expansion of private wells on rural livelihood (income) in a tank-intensive watershed in the upper Gundar River Basin in southern Tamil Nadu, India, based on data obtained by recent field surveys, government statistics and meteorological records. For the entire upper river basin, we show spatial differences at the village (*gram panchayat*) level and track the changes over the last two decades. The major finding is that although traditional crop production, mainly composed of paddy, millets and pulses, was dominant at least until the mid-1990s, the expansion of private wells enabled farmers to introduce cash crops, especially in the upper part of the basin. By contrast, fallow land increased sharply in the lower part of the basin due mainly to the disappointing performance of the wells. The different performance of wells finally resulted in a significant income gap between the upper and the lower river basin.

**Keywords:** tank irrigation, private well, commercial agriculture, farm income

### I Introduction

Based on tank (water reservoir) irrigation system, traditional rice-based agriculture has long been practiced in many parts of Tamil Nadu, India. Nowadays there are still 39,202 tanks in the state [Palanisami *et al.* 2008], which were constructed across the slope of valleys to catch and store water. These tanks have existed since “time immemorial” [Palanisami 2000]; one of the tanks in Madurai District, for instance, was constructed either in the later Pandiyas (1300AD–1600AD) or the Nayakas (1600AD–1800AD) period, deducing from its sluice structure and mortar [Ford Foundation and Anna University 2001]. Ludden [1979] argued that the civilization in Tamil Nadu matured amidst irrigated paddy fields which benefited from tank irrigation.

---

\* 佐藤孝宏, Center for Southeast Asian Studies, Kyoto University  
e-mail: takahiro@cseas.kyoto-u.ac.jp

\*\* Centre for Agriculture and Rural Development Studies, Tamil Nadu Agricultural University

It is well-known that minor irrigation, especially well irrigation, has played a critical role in agricultural development in India since independence (e.g., Esho [2008]; Sivasubramaniyan [2006]). This is also true for the tank-irrigated areas in south India, including Tamil Nadu. Expansion of private wells that were constructed in the command area of tanks for supplementary irrigation and also in the dry land for introducing irrigation have been leading agricultural development in such a region as well, primarily through increased yield per unit of land for traditional crops, mainly rice (through the “Green Revolution”). In recent years, the demand for rice in India has been approaching saturation point, enabling the country to start exporting rice to the world market. However, because of the relatively low productivity of rice in tank-irrigated areas (compared to Punjab, for instance), economic development through rice exports cannot be expected in such areas.

Given that almost half of the working population is still engaged in agriculture in Tamil Nadu [GOTN 2006a]<sup>1)</sup> and agricultural development is still one of the key issues for economic development, increased production of high-valued crops such as fruit and vegetables is essential in tank-irrigated areas. High-valued crops are mainly for urban population; their number has been rapidly increasing, especially after the early 1990s when India started full economic liberalization and thereby accelerated the development of industrial and service sectors (on Tamil Nadu, see Kajisa and Palanichamy [2006]). Considering that more ample and timely irrigation is indispensable for growing fruit and vegetables or other high-valued crops, the importance of private wells is also expected to grow. Tank water is stored only during the rainy season, and the water volume is highly affected by climate conditions as well as by tank management. By contrast, well water is available throughout the year, unless the well dries up. The expansion of private wells after independence, especially since the 1960s, significantly contributed to the “Green Revolution.” In Tamil Nadu, the “Green Revolution” spread mainly in the 1980s up to the mid-1990s (Fujita [2011] in this issue). It is also reported that groundwater irrigation started to expand again after the 1990s in the state mainly due to the decline in the price of pumps and the cost of drilling wells [Kajisa *et al.* 2007].

There are already a number of studies focusing on the expansion of private wells and its impact in Tamil Nadu (e.g., Janakarajan [1993]; Palanisami *et al.* [2008]). The important role played by private wells in agricultural development has been argued clearly but much attention has not been paid to the salience of geographical location of their study site, because their analyses were largely confined to individual villages or at most to some blocks (an administrative unit; see footnote 2)). For more sustainable

---

1) But the primary industry contributes less than 20% of net state domestic product in Tamil Nadu [GOTN 2006a], thus indicating the widening income disparity between urban and rural areas.

rural development, watershed development programs have become a key strategy in India [GOTN 2010; Shah 2000; Vaidyanathan 2006]. This means that when we deal with the expansion of private wells, analyzing the issue within a wider geographical context such as at a river basin level is essential.

This article focuses on the entire upper part of the Gundar River Basin in southern Tamil Nadu, which is one of the tank-intensive watersheds in the state. The major objective of the article is to investigate the effect of the expansion of private wells by examining the changes in crop choice by farmers during the last two decades from subsistence food crops (rice, millets and others) to cash crops. In other words, based on data obtained from government statistics and recent field surveys, we attempt to show how the expansion of private wells affected crop choice by farmers and their livelihood (income) in the entire upper Gundar Basin. Although we offer detailed analysis of only two study villages from the upper and the lower part of the basin, we illustrate the spatial variation at the village (*gram panchayat*) level by showing several GIS (geography information system) maps.

The next chapter of this article provides an overview of the research site, namely, the upper Gundar River Basin and the two study villages for an in-depth analysis. Then, the process of the expansion of private wells in the study area is illustrated in Chapter III. After brief explanations on crop cultivation in the studied four blocks in Chapter IV, we discuss the changes in crop choice and their impact on rural livelihood (income) in Chapters V and VI. Before the conclusion, we discuss some major points raised in this article in Chapter VII.

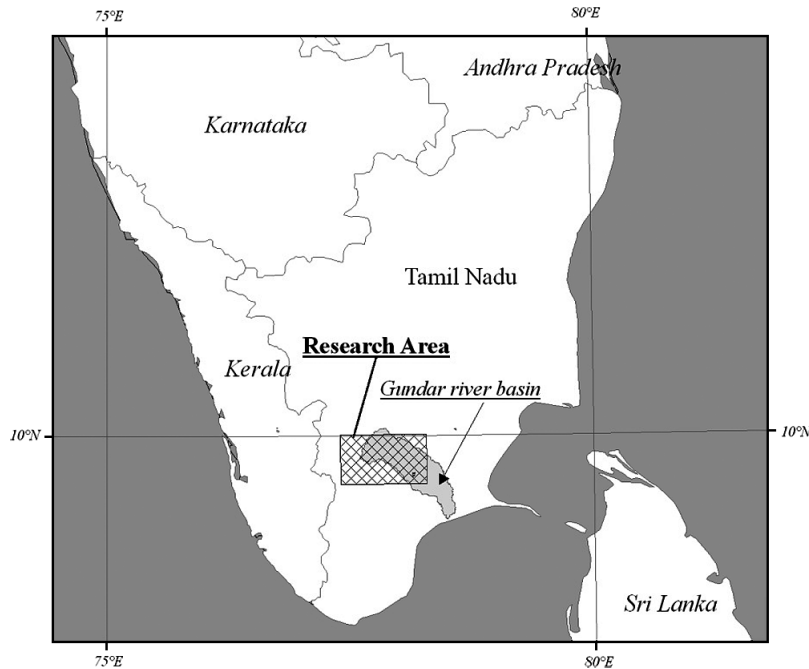
## II Overview of the Research Site

### II.1. *Outline of the Upper Gundar River Basin*

There are a total of 17 major river basins in Tamil Nadu, one of which is the Gundar River Basin (Fig. 1). It has a total area of 5,647 km<sup>2</sup>, extending to 5 districts [Gowtham and Lawrence 2010]. The upper part of the basin covers 3 blocks (Sedapatti, Tirumangalam and Kallikudi) of Madurai District and 1 block (Kariapatti) of Virudhunagar District (Fig. 2).<sup>2)</sup> In the interest of simplicity, Sedapatti, Tirumangalam, Kallikudi and Kariapatti blocks will be renamed according to their position in the basin as Blocks A, B, C and D, respectively. The upper Gundar River Basin is composed of the two major tributaries, i.e., Goundanathi and Thekkar. The Goundanathi River starts from the two villages of Saptur and Elumalai in Block A [GOTN 2008a]. The Goundanathi and Thekkar Rivers join at the P. Pudupatti Village in Block D, from where the river is called the Gundar [*ibid.*].

---

2) The “block” is an administrative unit in India introduced for the purpose of development after independence.



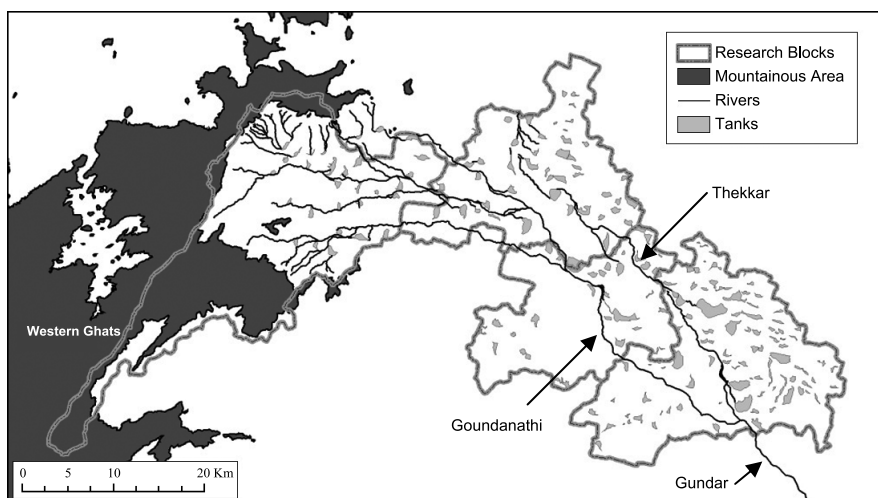
**Fig. 1** Location of the Study Area

As illustrated in Fig. 2b, the four blocks under study are located south to west of Madurai, the second largest city in Tamil Nadu. National highways extend radially from Madurai City, and state highways are arranged to connect to these national highways. There are four wholesale markets near the study area; Madurai, Tirumangalam, Usilampatti, and Virudhunagar [GOTN 2004]. The Madurai Wholesale Market is the biggest, reflecting the largest population size of the city.

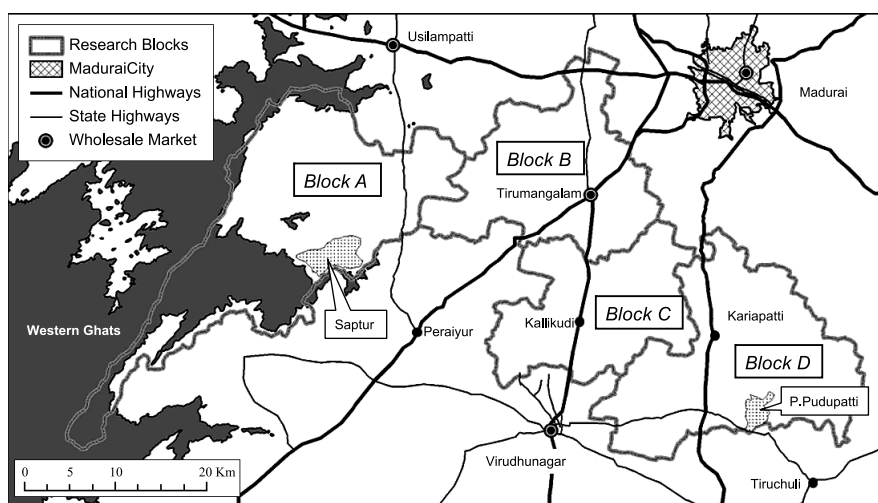
Table 1 presents the general characteristics of the four blocks. The total geographical area is 1,578 km<sup>2</sup>. The population density in Blocks A and D was lower than the other two, but the low density in Block A was mainly due to the existence of a large reserved forest. Since agricultural workers (including cultivators and agricultural laborers) occupied more than half of the total workforce, the agricultural sector still played a major role in the study area in general. However, out of the four blocks Block D was an exception, with more than half of non-agricultural workers.

Fig. 3 shows the average monthly rainfall, in comparison with the reference evapotranspiration ( $ET_0$ ) measured at Madurai AC & RI.<sup>3)</sup> The value of  $ET_0$  is generally treated as potential evapotranspiration, which is the amount of water that could be evaporated or transpired if sufficient soil

3) The monthly reference evapotranspiration ( $ET_0$ ) was calculated by the methodology of Allen *et al.* [1998].



(a) Topographic Features of Study Area



(b) Road Connections in Study Area

**Fig. 2** Maps of the Study Area

water was available. The figure shows that the  $ET_0$  exceeds the rainfall almost all the year round except during the three months from September to November, when the northeast monsoon brings relatively plentiful rainfall in the area. River flow can only be observed a few times in this rainy season (September–November) when it rained intensively. There is little river flow in the dry season (December and January–August) because most of the rainfall in this season has evaporated. The average rainfall of the whole study area in the 2005–06 agricultural year (June–May) was 913 mm,

**Table 1** General Characteristics of the Studied Blocks

	Area (km <sup>2</sup> )	Number of Revenue Villages	Total Population	Population Density (Person/km <sup>2</sup> )	Total Workers	Share of Total Workers (%)		
						Cultivators	Agricultural Laborers	Other Workers
Block A	600.70*	37	89,320	148.7	48,297	23.3	41.2	35.5
Block B	319.25	53	84,748	265.5	45,098	18.4	40.2	41.4
Block C	256.82	47	68,263	265.8	40,831	22.3	45.4	32.3
Block D	401.56	108	91,598	228.1	48,044	21.4	27.1	51.5
Total	1,578.33	245	333,929	211.6	182,270	21.4	38.1	40.5

Data source: GOTN [2006b; 2006d; 2006f; 2006h].

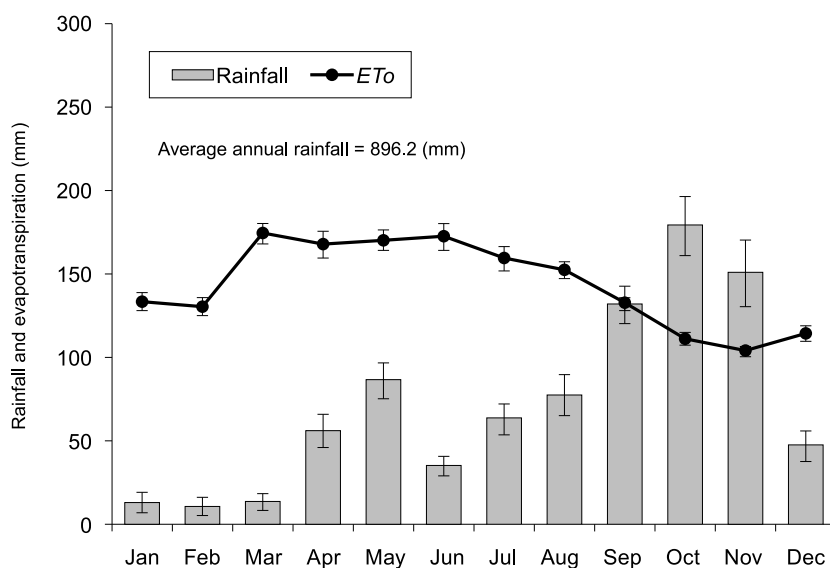
Note: \* Block A contains 242.23 km<sup>2</sup> of reserved forest.

whereas Fig. 4<sup>4)</sup> shows the spatial distribution of it in the entire upper Gundar Basin.<sup>5)</sup> The northern part of Block A recorded the highest level, with an average of more than 1,200 mm. The rainfall gradually decreased towards the lower part of the basin and reached less than 800 mm in the southeastern part of Block D. The block-wise average rainfall in 2005–06 was 1,222 mm, 1,132 mm, 1,056 mm, and 856 mm in Blocks A, B, C, and D, respectively. Note that the rainfall amount in the year 2005–06 was slightly higher than the normal year, deducing from its record in Tirumangalam Town. The average annual rainfall from 1980–01 to 2005–06 was 913.2 mm, compared to 1,084 mm in 2005–06.

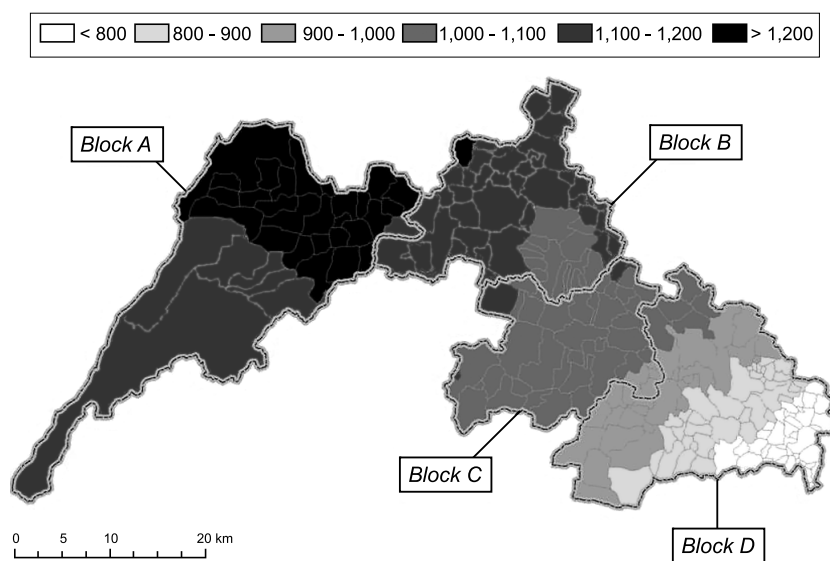
Similar to the other areas in Tamil Nadu, tank irrigation system has long been developed in the study area to conserve available water for irrigation. According to the official record there were a total of 2,302 tanks in the entire Gundar River Basin [GOTN 2008a], 219 of which were located in the study area (the upper part of the basin). The number of tanks was 30, 47, 36, and 106 in the four blocks (Blocks A, B, C, and D), respectively (Fig. 2a). The density of tanks was highest in Block D because, as shown in the figure, the lower part of the basin had more tanks. In general, there are two water sources for tank irrigation systems: one is the water flowing from a channel connected to a river, and the other one is the runoff water from the catchment area. Out of a total of 219 tanks in the study area, 118 tanks are connected to a river [GOTN 2009a; 2009b]. Out of these 118 tanks, 45 tanks are connected to the

4) All geographical figures presented in this paper were made by *ArcGIS*. Location of the cities, river flows, and tanks were visually interpreted according to the field survey using *Google Earth Pro*.

5) The daily rainfall data from April 1979 to August 2008 was collected from the Public Works Department (PWD) office, Virudhunagar District office, Peraiyur *Taluk* office, Thirmangalam *Taluk* office, Usilampatti *Taluk* office, and Madurai Agricultural Collage and Research Institute (Madurai AC & RI) of Tamil Nadu Agricultural University (TNAU). For estimating the spatial distribution of annual rainfall in the study area, the data of 10 rainfall stations, namely, Aruppukottai (9°31'N, 78°06'E), Madurai AC & RI (9°54'N, 78°80'E), Madurai Airport (9°50'N, 78°05'E), Peraiyur (9°44'N, 77°47'E), Peranai (10°06'N, 77°48'E), Tiruchuli (9°32'N, 78°12'E), Tirumangalam (9°49'N, 77°59'E), Usilampatti (9°54'N, 78°80'E), Vaigai Dam (10°03'N, 77°35'E), Watrap (9°38'N, 77°38'E), were used. The spline interpolation method was applied to these data using *ArcGIS* and *Spatial Analyst*.



**Fig. 3** Monthly Rainfall and Reference Evaporation ( $ET_0$ ) in Madurai (averaged of 1980–2006)  
Data source: Weather data at Madurai AC&RI, Tamil Nadu Agricultural University  
Note: Vertical bars denote standard error.



**Fig. 4** Spatial Distribution of Annual Rainfall in 2005–06 Agricultural Year (unit: mm/year)  
Data source: Rainfall data at 10 rainfall stations (See text)



Vaigai River which flows outside the Gundar River Basin. They are located in the northern part of Blocks B and D. A continuous river flow throughout the year can be expected in the Vaigai River because of the existence of the two large reservoirs [Sivasubramaniyan and Vaidyanathan 2001], so that the period when water is stored in these 45 tanks is much longer; interview with farmers revealed that water is normally stored from mid-October to the end of March (5.5 months). The remaining 73 system tanks benefit from the Goundanathi or Thekkar River, and the tank water is normally stored only for three months. Finally, the remaining 101 tanks are completely rain-fed; runoff water from the catchment area is the only source of water. They are the most unstable tanks.

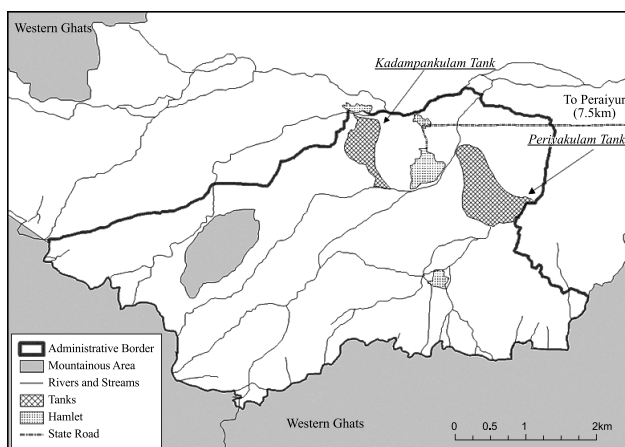
## II.2. *Outline of the Study Villages*<sup>6)</sup>

For an in-depth study we selected two villages from the study area: one from the upper part of the basin and the other from the lower part of it. The former village named Saptur Village is located in the western part, belonging to Sedapatti Block (Block A) of Madurai District (Fig. 2b). It is located 7.5 km away from Peraiyur Town, where the *taluk* office is located.<sup>7)</sup> The total population of the village was 7,767 [GOTN 2006b], and almost 80% of the population lived in Saptur Hamlet, the biggest hamlet among the six hamlets in the village. More than 70% of the workforce was engaged in agriculture and related activities [*ibid.*]. The village is very close to the Western Ghats Mountains, and sits in the uppermost part of the Gundar Basin (Figs. 2b and 5a). There are two tanks in the village that irrigate the wet land in the tank command area (*nañcai* in Tamil) located in the northeastern part of the village. However, most of the agricultural land owned by the villagers is categorized as dry land (*puñcai* in Tamil), falling outside of the tank command area. A number of small rivers originating from the Western Ghats flow through the *puñcai*, and some farmers who owned land adjacent to the small rivers may take the water into their land for irrigation. The rainfall was recorded at 1,238 mm in Periyar Town in 2005–06.

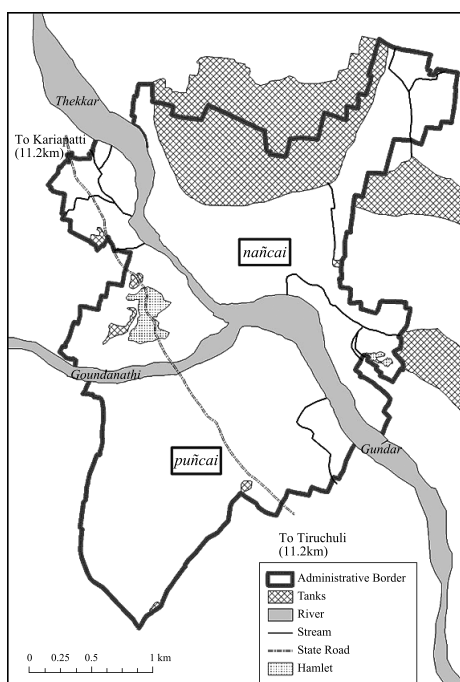
The other study village named P. Pudupatti (the official name is Perunjaripudupatti) Village is located in the southeastern part of the study area, belonging to Kariapatti Block (Block D) of Virudhunagar District. It is located 11.2 km from Tiruchuli Town, where the *taluk* office is located. The total population of the village was 1,150 [GOTN 2006h], and almost 90% of the population lived in Pudupatti Hamlet (The other small hamlet is called Perunjari Hamlet). More than 60% of the workforce was engaged in agriculture and related activities [*ibid.*]. As mentioned earlier, the two tributaries of the Gundar River

6) In this paper a village means an administrative unit officially called *gram panchayat*. A *gram panchayat* is usually composed of several hamlets (natural villages).

7) The *taluk* is an administrative unit introduced mainly for revenue collection in the British colonial era. Generally, a *taluk* covers a wider area than a block in Tamil Nadu.



(a) Saptur Village



(b) P. Pudupatti Village

**Fig. 5** Maps of the Study Villages

(Thekkar and Goundanathi) join at this village (Figs. 2a and 5b). There is only one tank, which is connected to the Thekkar River. The tank irrigates *nañcai* land located in the south. *Puñcai* land extends widely to the southwestern side of the Thekkar/Gundar Rivers. The rainfall was recorded 720 mm in Tiruchuli Town in 2005–06.

### III Process of Expansion of Wells in the Study Area

The spatial distribution of the density of dug wells in the entire study area is shown in Fig. 6. The density of dug wells was highest in Block A, whereas in the two blocks located in the middle reach of the basin (Blocks B and C), villages with high and low densities of dug wells form a mosaic. The density of wells was apparently low in Block D.

Now, in order to investigate the inter-temporal process of the expansion of private wells in the study area, two kinds of data are presented here. One is the data from the government statistics (confined to Madurai District) and the other is from the authors' field surveys in the two study villages.

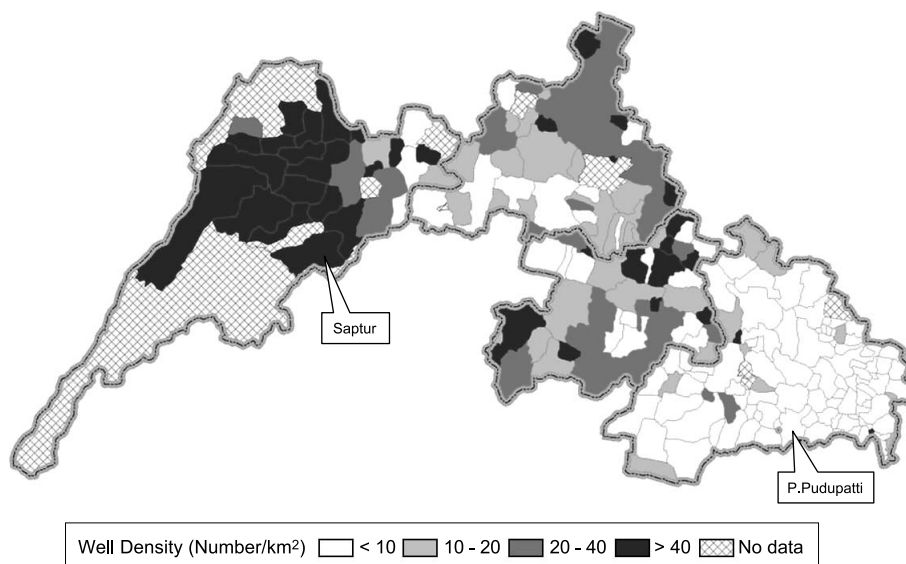
Fig. 7 shows the change in the number of wells, including dug wells and bore wells<sup>8)</sup> in Madurai District during the last two decades. The figure shows that the number of both dug and bore wells showed a slow increase until the end of the 1990s, but the speed of the increment suddenly accelerated in the early 2000s. However, a sharp decline in the number of dug wells was observed from the mid-2000s, which might reflect the abandonment of existing wells.

Next, let us examine the experiences in the two study villages regarding the change in the number of private wells. Table 2 shows the trend in Saptur Village. It is found that in *nañcai*, the number as a whole did not change, but dug wells were rapidly converted to dug-cum-bore wells after the mid-1990s. By contrast, the number of wells in *puñcai* increased rapidly from the late-1990s due to the increase of both dug-cum-bore wells and bore wells. On the whole, the total number of private wells in the village showed an increase from 1998, and the depth of wells became deeper due to the conversion of dug wells to dug-cum-bore wells. Regarding P. Pudupatti Village, a land registration map in 2008 suggested that there existed 43 wells within the village boundary, but according to our field survey in 2008, in *nañcai* there were only 10 active dug wells in 1998. Five were newly installed by 2008, but none of these was in use in 2008. The reasons for the abandonment of wells were due to both a shortage of groundwater and a problem with its salinity.<sup>9)</sup> It should be mentioned here that one farmer installed a bore well down to around 350 feet from the soil surface in 1998, but could not obtain any water. On the other hand, in *puñcai* there were only 2 dug wells in use in 2008; and the rest of the wells were also abandoned.

We observed a strong tendency toward the decrease of the density of wells from the upper to the lower basin in accordance with the river flow (Figs. 2a and 6), which might correspond to the different

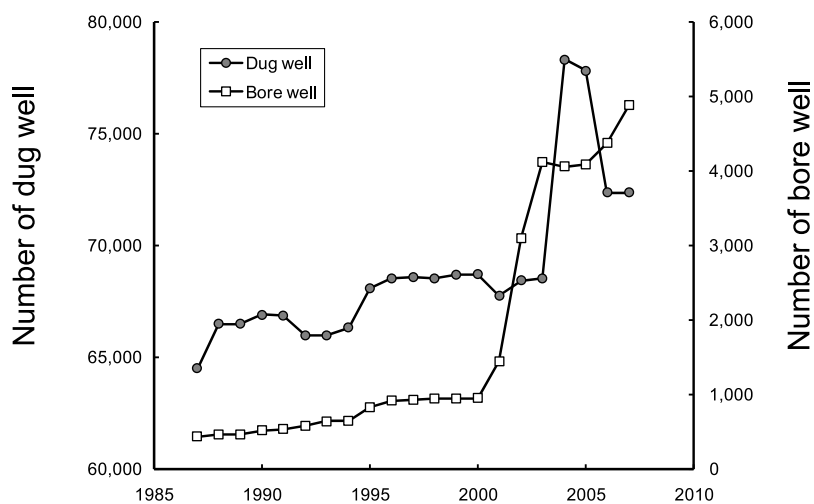
8) See Appendix, regarding the definition of wells. Data on dug-cum-bore well was also presented in the statistical data, but we did not present it because of its apparent inaccuracy.

9) We observed salinity problems of groundwater in the lower part of the basin, including P. Pudupatti Village, even though the village is not close to the sea.



**Fig. 6** Spatial Distribution of the Density of Dug Wells

Data source: GOTN [2006c; 2006e; 2006g; 2006i]



**Fig. 7** Inter-temporal Changes in the Number of Private Wells in Madurai District\*

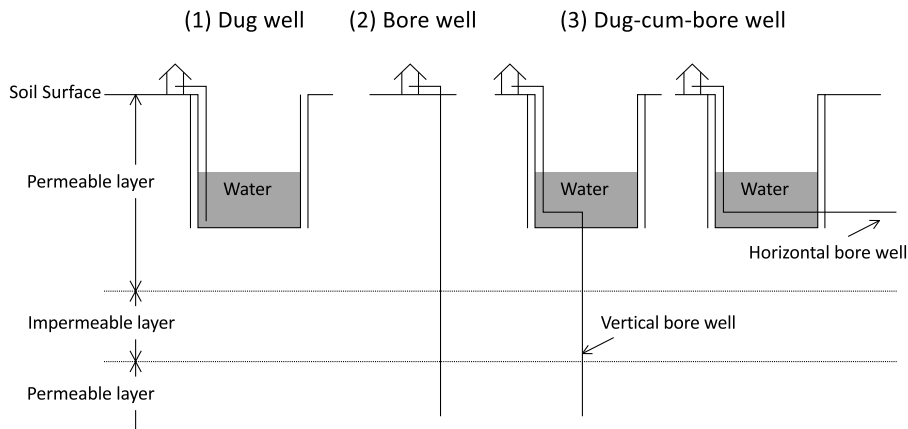
Data source: *Season and Crop Report of Tamil Nadu* [various issues]

Note: \* Number of wells in Madurai and Theni Districts were aggregated because Theni District was separated from the original Marudai District in 1996.

**Table 2** Inter-temporal Changes in Private Wells in Saptur Village (Number of samples=58)

Land Type	Well Type	1988	1993	1998	2003	2008
<i>nañcai</i>	Dug well	22	21	20	17	16
	Dug-cum-bore well	1	2	5	8	9
	Bore well	0	1	1	1	1
	Total	23	24	26	26	26
<i>puñcai</i>	Dug well	29	25	23	22	20
	Dug-cum-bore well	4	8	13	17	21
	Bore well	0	0	1	4	6
	Total	33	33	37	43	47
Total	Dug well	51	46	43	39	36
	Dug-cum-bore well	5	10	18	25	30
	Bore well	0	1	2	5	7
	Total	56	57	63	69	73

Data source: Author's field survey (December, 2008)

**Fig. 8** Type of Wells

performance of wells. According to data on groundwater level surveyed in May 2006 [GOTN 2007a; 2007b], which is expected to be the lowest in the whole year because of the pre-monsoon season, the groundwater level was 2 to 5 meters in the three blocks located in the upper basin (Blocks A, B, and C), and 5 to 10 meters in Block D. Given the fact that, as shown in Fig. 8, the permeable layers and impermeable layers are alternately stratified under the soil surface, these figures seemed to be the groundwater level just under the soil surface, from which dug wells can be recharged. The lower groundwater level in Block D suggested above, therefore, indicates that farmers in Block D had to dig dug wells deeper, just in order to get the same amount of water, compared to the other three Blocks. On

**Table 3** Summary of Cropping in the Studied Blocks (2005–06 Agricultural Year)

Block	Total Agricultural Area (ha)	Gross Cultivated Area (ha)	Cropping Intensity (%)	Gross Irrigated Area (ha)	Irrigation Ratio (%)
A	23,352	14,353	61.5	7,421	51.7
B	22,737	13,699	60.2	5,438	39.7
C	15,518	13,907	89.6	5,358	38.5
D	33,305	13,998	42.0	9,146	65.3
Total	94,912	55,908	58.9	27,393	49.0

Data source: GOTN [2006c; 2006e; 2006g; 2006i]

the other hand, bore wells capture groundwater from the deep permeable layer. We have already introduced above the story of a farmer in P. Pudupatti Village who failed to get water from the depth of around 350 feet ( $\approx$ 107 meter), which implies that farmers in the lower basin generally faced difficulties to get groundwater from the deep layer as well. Such difficulties faced by farmers in the lower basin made them hesitate to install new wells, and resulted in the spatial deviation of wells as shown in Fig. 6.

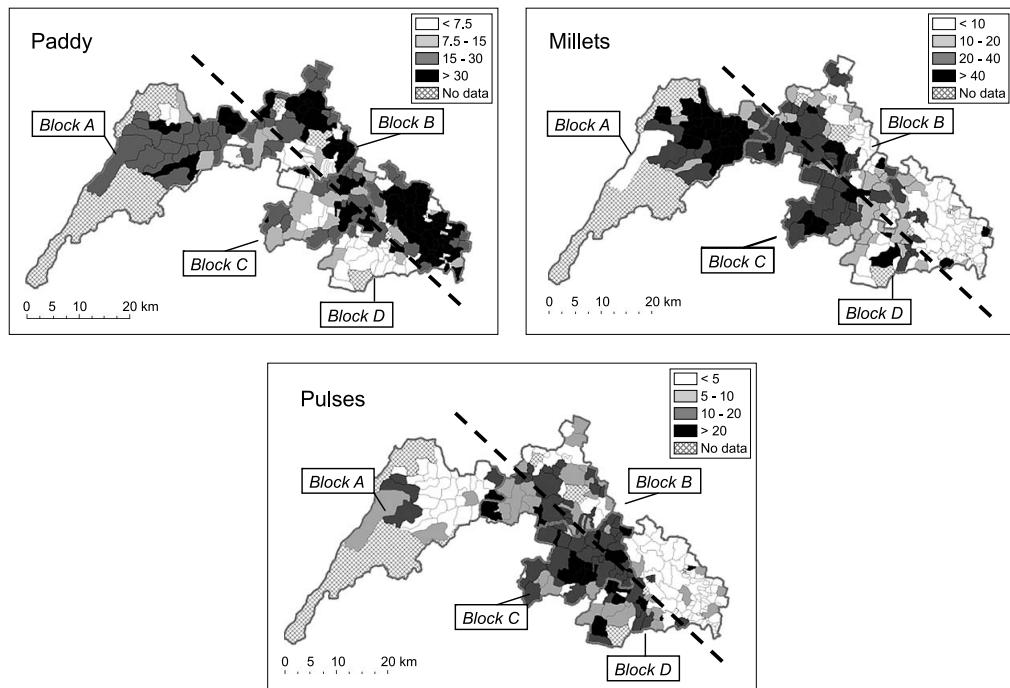
#### IV Spatial Differences in Cropping System within the River Basin

Table 3 is a summary of cropping in the four Blocks in the 2005–06 agricultural year. We found that even though there was a total of 94,912 hectares of agricultural land, the gross cultivated area was only 55,908 hectares, with a cropping intensity of 58.9%; and the share of land lying fallow was large. Cropping intensity was the highest in Block C (89.6%) and the lowest in Block D (42.0%). The average irrigation ratio was 49.0%, whereas it was relatively high in Block D (65.3%) and A (51.7%).

Fig. 9 shows the spatial distribution of the “cultivation share” for subsistence food crops such as paddy, millets,<sup>10)</sup> and pulses. The spatial distribution of the cultivation share for cash crops such as fibers, oil crops, sugarcane, and fruit/vegetables is presented in Fig. 10. Note here that, given the fact that tanks were concentrated in the northern side of the Thekkar River (Fig. 2a), the dashed lines in Figs. 9 and 10 separate the study area by the density of tanks. In the following part of this chapter, let us refer to the area above and below the line as the “Tank-zone” and the “Rain-fed-zone,” respectively.

Now the major question is what kind of factors determined the crop choice by farmers, which was quite different in each geographical unit, as shown in Figs. 9 and 10. The hypothesis here is that water availability in each unit vis-à-vis water requirement for different crops was the major determinant. Let us now examine this issue in depth.

10) Major millets in the study area include sorghum (*cholan* in Tamil), pearl millet (*cumbu*), finger millet (*ragi*), and maize.



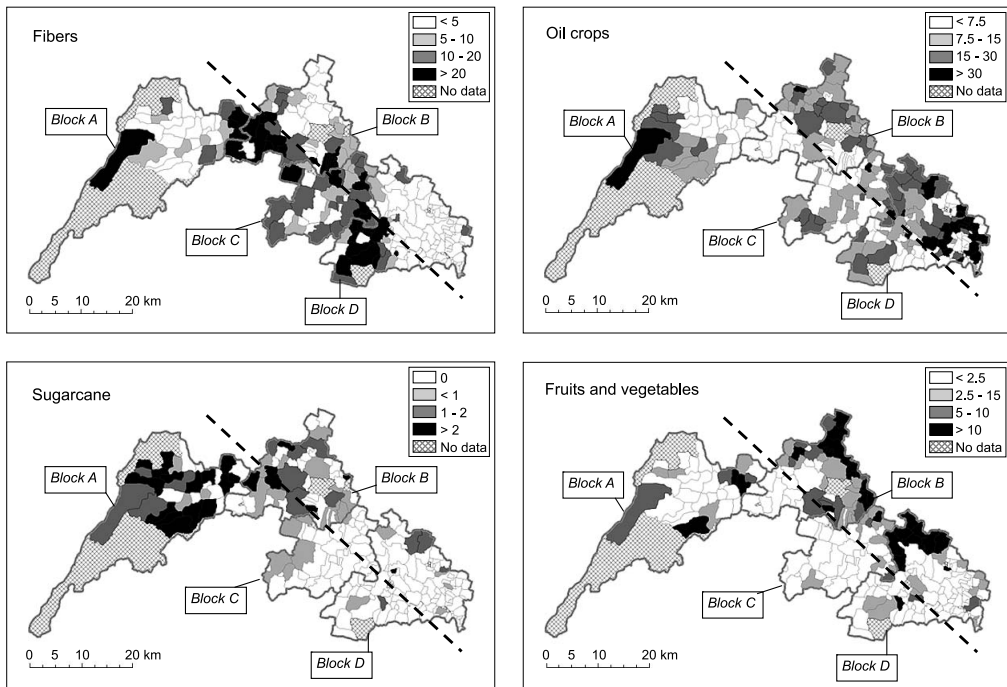
**Fig. 9** Spatial Distribution of Cultivation Share\* of Subsistence Food Crops (2005–06 Agricultural year)

Data source: GOTN [2006c; 2006e; 2006g; 2006i]

Note: \* Cultivation share = (Area under each crop) / (Total cultivated area)

Generally speaking, almost all the farmers in the study area grow paddy during the rainy season in *nañcai*, but some farmers with well-functioning wells grow paddy in *puñcai*, and in *nañcai* during the dry season, as well. In Fig. 9, a high cultivation share of paddy was mainly observed in the Tank-zone, but a relatively higher cultivation share (of paddy) was also noted in Block A. Millets were the traditional crops during the rainy season in *puñcai*, but many farmers now grow them in the dry season as well. Millets are usually grown under rain-fed conditions, but farmers with wells give supplementary irrigation. According to our interview with farmers the gruel made from millets was commonly used as a staple food until 20 to 30 years ago. Currently, they mainly use millets for feeding cattle. Higher cultivation share of millets was observed in the Rain-fed-zone, especially in Blocks A, B and C. Pulses such as red gram and black gram are common food crops in the study area, and also used for making *saanbar* (South Indian vegetable curry sauce), etc. We also observed a higher cultivation share of pulses in the Rain-fed-zone, especially in Blocks B, C and D.

In Fig. 10, a higher cultivation share of fibers (mainly cotton) was evident in the Rain-fed-zone (Blocks B, C and D), similar to pulses. By contrast, we observed a higher cultivation share of oil crops



**Fig. 10** Spatial Distribution of Cultivation Share\* of Cash Crops (2005–06 Agricultural year)

Data source: GOTN [2006c, 2006e, 2006g, 2006i]

Note: \* Cultivation share = (Area under each crop) / (Total cultivated area)

(mainly groundnut) in the Tank-zone. Fibers and oil crops were usually cultivated during the dry season under irrigation when well water is available. Relatively minor cash crops such as sugarcane and fruit/vegetables displayed a unique spatial distribution. A high cultivation share of sugarcane can be seen in the upper part of the river basin. Sugarcane farmers in the study area had wells without exception, because it was one of the necessary conditions for making a contract with sugarcane factories. The growing period of sugarcane is two years (newly planted and ratoon). For fruit/vegetables, we observed a high cultivation share only in the villages at the northeastern edge of the Tank-zone. Vegetables were grown during the dry season under well irrigation because of the necessity for ample and timely irrigation.

Table 4 shows the estimated standard water requirement ( $ET_c$ ) (maximum amount of water use under favorable soil water conditions) for the major crops in the study area.<sup>11)</sup> The  $ET_c$  is mainly

11) For estimating the  $ET_c$ , a monthly summary of weather data (rainfall amount, maximum and minimum temperature, relative humidity, sunshine hours or radiation, and wind velocity) during 1980–2005 (the data for 2001 were not available) measured at Madurai AC & RI, TNAU was used. The growing period of crops were obtained from our interviews with farmers as explained above, on a monthly basis. Crop evapotranspiration was estimated using single crop coefficient ( $k_c$ ) [Allen *et al.* 1998] and presented as the standard water requirement. Estimated values were the averages during 1980–2005.



**Table 4** Standard Water Requirement for Major Crops in the Study Area

Subsistence Food Crops / Cash Crops	Category	Kind of Crop	Major Growing Period	Standard Water Requirement (mm)
Subsistence Food Crops	Paddy	Paddy	Oct–Jan	1200.6±239.9
	Millets	Sorghum	Apr–Jul	441.8±119.3
	Pulses	Green gram	Mar–May	291.0±80.6
	Fibers	Cotton	Mar–Aug	811.5±213.5
	Oil crops	Groundnut	Jan–Apr	495.9±131.4
Cash Crops	Sugar crops	Sugarcane	Apr–Mar	1813.2±423.8
	Fruits and vegetables	Banana	Apr–Mar	1657.8±387.4
		Fruit trees	–	1157.0±270.4
		Vegetables	Jun–Aug	438.4±119.1

Note: The values were calculated using the weather data at Madurai AC & RI, Tamil Nadu Agricultural University following Allen *et al.* [1998].

Average numbers from 1980 to 2005 were presented.

Numbers after “±” indicate standard error.

Shading values in table indicate popular growing period in the study area.

determined by the length of growing period and the dryness of the air during the growing period. The crop-wise orders (from high to low) of the estimated  $ET_c$  were paddy > millets > pulses for the subsistence food crops, and sugarcane > fruit tree > fiber > oil seed > vegetables for the cash crops. The crops with high  $ET_c$  such as paddy, sugarcane and fruit/vegetables will naturally require irrigation, either from tanks or wells.

To sum up the argument, firstly, the spatial distribution of crops in the study area was primarily determined by the availability of tanks, because the cultivation share of paddy and oil crops was relatively high in the Tank-zone, whereas that of millets, pulses and fibers was relatively high in the Rain-fed-zone. However, secondly, differences in the cropping system within the same zone (either in the Tank-zone or the Rain-fed-zone) were also evident. Fruit and vegetables, which require ample and timely irrigation, for instance, were introduced only in the villages located at the northeastern edge of the Tank-zone, because the tanks in these villages kept water for longer periods due to their connection to the large-scale reservoirs, as explained earlier in Chapter II, although the vicinity to market (Madurai City) was another major reason. In the Rain-fed-zone, paddy and sugarcane, which required more water (Table 4), were introduced only in the uppermost part of the basin (Block A), because many farmers in Block A had wells, which might enable them to supply enough water to the crops with high water requirement. Also notable is the fact that the crops selected in Blocks B, C and D were similar (such as millet, pulses and fibers), but the irrigation ratio of these crops in Block B was apparently

**Table 5** Irrigation Ratio of Selected Crops in the Studied Blocks (2005–06 Agricultural Year)

Block	Millets	Pulses	Fibers	Oil Crops	Total
A	79.0%	66.9%	26.5%	36.6%	57.2%
B	52.8%	99%	81.3%	63.6%	71.4%
C	3.2%	0.1%	2.0%	20.1%	5.3%
D	10.7%	20.1%	2.9%	12.1%	10.3%
Total	26.6%	24.1%	10.6%	25.5%	21.3%

Data source: GOTN [2006c; 2006e; 2006g; 2006i]

higher than in Blocks C and D (Table 5), because the wells in Block B might provide more water than those in Blocks C and D. The cropping intensity was apparently higher in Block C than Block D (Table 3), which implied that water used for crop cultivation was larger in Block C than in Block D because of the different well density between Blocks B and C. Therefore, the spatial differences in the cropping system presented in Figs. 9 and 10 can be understood mainly by the factor of water. Water availability was originally determined by tanks, but the availability of wells also became a major determinant of crop choice in the study area.

## V Differences in the Crop Composition between Upper and Lower Basin<sup>12)</sup>

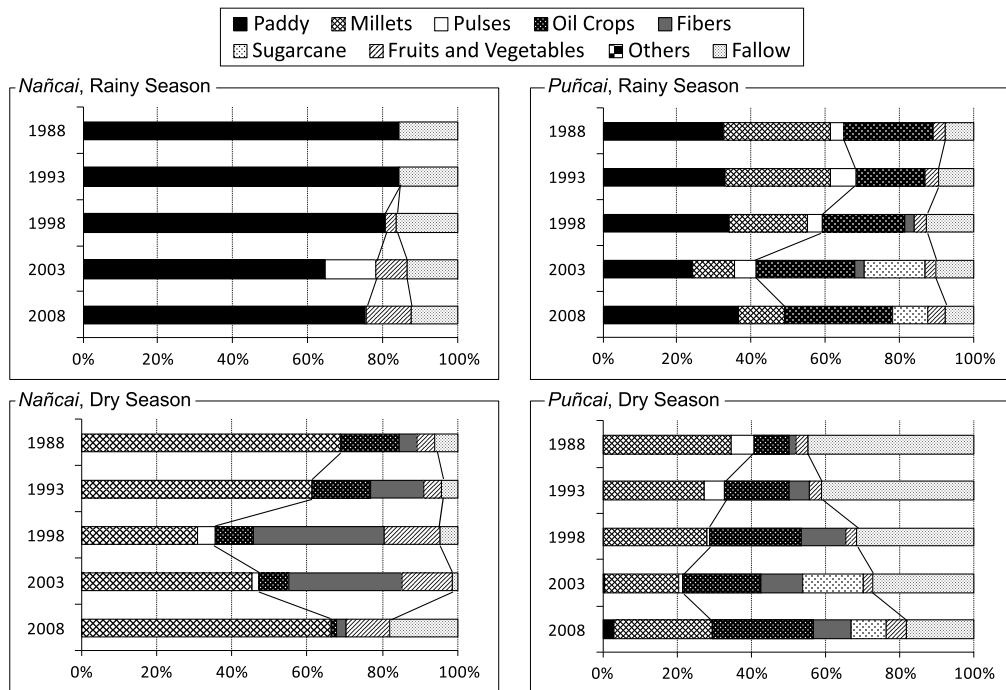
The changes in the crop composition in the two study villages during the last two decades are shown in Figs. 11 and 12, by using data obtained from the sample farmers (58 and 22 from Satpur and P. Pudupatti Villages, respectively) on area of crops cultivated, which were added up and presented as a share of crops in each village. Here, crops are categorized into two (subsistence food crops and cash crops) and the share of fallow land is also shown. Now let us present the major findings for each village, and by the category of land (*nañcai* and *puñcai*).

### (1) Saptur Village

#### 1) *Nañcai*

In the rainy season, the cultivation of subsistence food crops continued to be highly dominant, but a

12) The authors visited the study villages (Saptur and P. Pudupatti) in September and December, 2008, to collect detailed household-level data. The sample size of the households surveyed was 58 and 45 each. Details on cropping system, private wells, and household income for the year of 2007–08 were obtained through interviews and questionnaire surveys. The size of land holding and the area under each crop (including leased-in land and mortgaged-in land) during the last 20 years were also investigated. Because of the time limitation, however, the number of samples for this question was limited to 22 (out of 45) in P. Pudupatti Village.



**Fig. 11** Inter-temporal Changes in Crop Choice in Saptur Village

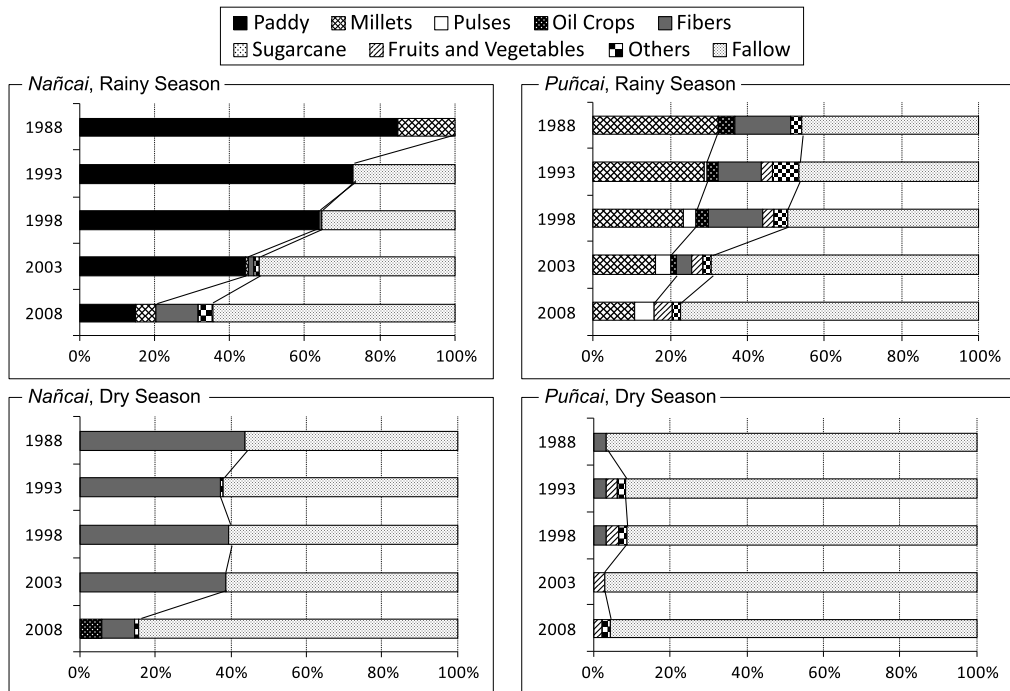
Data source: Author's field survey (December, 2008)

Note: Lines between the bar graphs illustrate the inter-temporal change of the share of the three crop categories (Subsistence food crops, Cash crops and Fallow) presented in Figs. 9 and 10.

gradual decrease in the area under paddy can be observed from 1998, as farmers shifted to cash crops (mainly banana). Banana cultivation increased its share until 2008. On the other hand, in the dry season, millet cultivation was originally dominant, but a remarkable change occurred from 1998, when almost half of the area under millets was converted to cash crops (fibers and fruit/vegetables). In 2008, however, cash crops (oil crops and fibers) declined and shifted back to millets, while fruit/vegetables remained the same. The ratio of fallow land decreased constantly until 2003, but increased sharply thereafter and reached nearly 18% in 2008.

## 2) *Puñcai*

In the rainy season, paddy, millets and oil crops were originally dominant. A noticeable change was observed with the introduction of sugarcane in 2003, which mainly replaced paddy and millets. However, sugarcane area decreased in 2008 and farmers converted back to paddy. In the dry season, nearly 50% of land remained fallow in 1988, but the cropping ratio increased continuously until 2008. Fallow



**Fig. 12** Inter-temporal Changes in Crop Choice in P. Pudupatti Village

Data source: Author's field survey (September, 2008)

Note: Lines between the bar graphs illustrate the inter-temporal change of the share of the three crop categories (Subsistence crops, Cash crops, and Fallow) presented in Figs. 9 and 10.

land was converted mainly to cash crops (fibers, oil crops and sugarcane). Millets were originally dominant, but as of 1993, some of them were also converted to oil crops and fibers.

## (2) P. Pudupatti Village

### 1) *Nañcai*

During the rainy season paddy cultivation was highly dominant in 1988, which covered more than 80% of the total area. The rest of the area was occupied by millets and there was no fallow land in 1988. After that, however, paddy cultivation declined continuously and especially sharply since 2003. Some of the areas under paddy were converted to fibers, millets and others, but more than 60% of land remained fallow in 2008, even in the rainy season. In the dry season, on the other hand, fibers (cotton) was extensively grown in 1988, occupying more than 40% of gross area. However, it also decreased sharply in 2008 and even though some areas under cotton were converted to oil crops and others, fallow land increased to nearly 85% in 2008.

## 2) *Puñcai*

A sharp decline in cultivation was also observed in *puñcai* land. Originally, millets, fibers and oil crops occupied nearly 50% of the cultivable land in the rainy season. However, from 2003, these crops were gradually abandoned and declined sharply, with land remaining fallow. The fallow land occupied 77% and 96% of *puñcai* land in the rainy and dry seasons, respectively, in 2008.

To sum up, from 1998, in Saptur Village, remarkable changes in crop choice occurred. First, millets cultivation during the dry season in *nañcai* shifted to fibers. Then, in 2003, sugarcane was introduced in *puñcai*. In both cases, the kind of crops introduced required more water than the originally cultivated crops (Table 4). The timing of the introduction of new crops coincided with that of the expansion of wells in the village (Table 2). Considering such correlations, we think it highly plausible that the change in the cropping system in the village became possible through the introduction of new wells or upgrading of existing wells. On the other hand, crop cultivation in P. Pudupatti Village continuously declined. The first decline occurred in *nañcai* during the rainy season in 1993, which continued until 2008. This decline might correspond to the decline in water storage capacity of the tank in the village from 1993 onward. After that, the second decline occurred in *puñcai* during the rainy season in 2003, followed by the decline in *nañcai* during the dry season. Finally, most of the cultivable land was left fallow. It seems that after 2003, such a decline was caused by the disappointing performance of wells in the village, as we discussed in Chapter III.

## VI Differences in Farm Income between Upper and Lower Basin<sup>13)</sup>

In the previous chapter, we illustrated the different patterns of agricultural transformation between the upper and the lower basin, and suggested that it might be caused by differences in the performance of wells, depending upon the geographical location within the basin. In this chapter, we investigate the

---

13) Estimates of household income were undertaken as follows. Income sources were divided into three: farm income, off-farm income and non-farm income. Each income was estimated separately in the rainy season (October–December) and the dry season (January–September). For estimating farm income, data on the size of cropped areas, yield, and farm gate prices were obtained for each crop grown in both *nañcai* and *puñcai*. Since we could not estimate the cost of production, we assumed the ratio of net income to gross revenue to be 60% uniformly, regardless of crops. The value of crops consumed by farmers was included in the farm income. Off-farm income was composed of income from agricultural wage labor and animal husbandry, and the latter was composed of income from sales of animals (sheep and goats) and milk from cows. We assumed that three kids are born to an adult female sheep/goat in two years, and annual increment of value per head was assumed to be Rs.3,000. Therefore, income from sale of animals is estimated from the number of livestock holding multiplied by the prevailing unit price (Rs.4,500 per head). There were some farmers engaging in goat/sheep tenancy, called *pangu-varam* in Tamil. In this contract, owners and tenants share 50% of income from selling sheep/goats. In estimating income, cash money provided by owners was treated as an income of tenants.

**Table 6** Annual Income and Its Components in the Two Study Villages

Village Name	Annual Income (10 <sup>3</sup> Rs.)	Component of Annual Income		
		On-farm Activities (10 <sup>3</sup> Rs.)	Off-farm Activities <sup>1)</sup> (10 <sup>3</sup> Rs.)	Non-farm Activities (10 <sup>3</sup> Rs.)
Saptur (n=58)	100.8±13.4**	66.5±11.1**	16.2±2.8	18.0±4.4
P. Pudupatti (n=45)	59.1±6.1	12.9±3.0	27.8±3.7*	17.0±5.4

Data source: Author's field survey (September and December, 2008)

Note: Numbers after “±” indicate standard error.

<sup>1)</sup> Off-farm activities indicate agricultural wage labor works and works related to animal husbandry.

\* Indicates significant difference at 5% level.

\*\* Indicates significant difference at 1% level.

effect of such differences in the crop choice on farmers' income. The estimated annual income and its breakdown into farm income, off-farm income (income from agricultural wage labor and animal husbandry) and non-farm income in the two study villages (for the 58 and 45 sample farmers in each village) are shown in Table 6 and the details of farm income are also shown in Table 7.

The tables show that 1) the income of Saptur Village was significantly higher than that of P. Pudupatti Village, which is mainly attributed to the large difference in farm income and; 2) farm income both in *nañcai* and *puñcai* and both in the rainy and the dry seasons was much higher in Saptur Village. Such a large gap in farm income was created by the difference in crop choice (Figs. 11 and 12). However, it should be noted that the major reason why off-farm income in P. Pudupatti Village was significantly higher than in Saptur Village lies in the fact that the invader trees called *Prosopis juliflora* grew densely in the fallow land and could be cut every 2–3 years for sale as charcoal or firewood. Our interview with farmers in 2008 revealed that since the price of the wood increased 5 times during the last 5 years, landowners with fallow land received Rs.2,000–15,000/acre (Rs.5,000–37,500/hectare) without any major cost. This wild tree also provided the villagers with opportunities for work during the dry season. The fact that non-farm income in P. Pudupatti Village was not larger than in Saptur Village suggests the reluctance of farmers in the lower river basin to seek other income sources, and their being “satisfied” with the low income.

Fig. 13 shows the relationship between the volume of well water used for irrigation and the income from crops.<sup>14)</sup> The sample size was 22. The figure shows that 1) there was a significant positive linear

14) To investigate the relationship between well irrigation and income from production of crops in the study area, in addition to the two study villages, the authors also visited five selected villages located in the same river basin in September 2008. Detailed data on the cropping calendar, irrigation frequency, and hours irrigated per time both in the rainy and the dry seasons were obtained from interview surveys. Based on information and data collected, the irrigated hours for each crop during the whole growing period were estimated. In estimating the actual amount of irrigation, irrigation hours were uniformly multiplied by 26.4 m<sup>3</sup>/hour, which was estimated by the authors through a direct measurement in a selected well from the study area.

**Table 7** Farm Income in the Two Study Villages

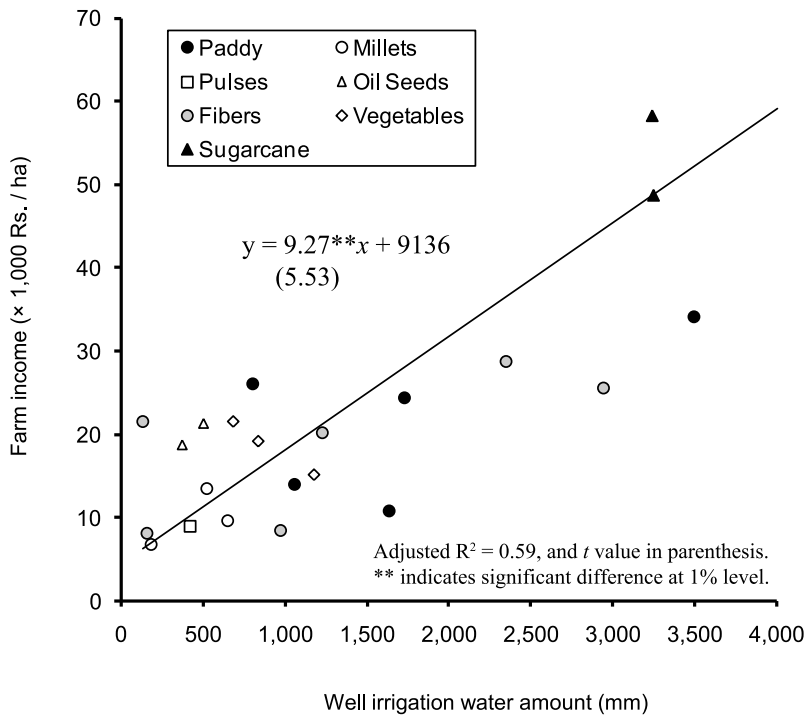
Village Name	Total	<i>Nattai</i>					<i>Pattai</i>				
		Land Holding (Ha)	Sub Total (10 <sup>3</sup> Rs.)	Rainy Season (10 <sup>3</sup> Rs.)	Dry Season (10 <sup>3</sup> Rs.)	Annual Crops (10 <sup>3</sup> Rs.)	Land Holding (Ha)	Sub Total (10 <sup>3</sup> Rs.)	Rainy Season (10 <sup>3</sup> Rs.)	Dry Season (10 <sup>3</sup> Rs.)	Annual Crops (10 <sup>3</sup> Rs.)
Saptur (n=58)	66.5±11.1**	0.38±0.08	16.6±3.4 *	11.2±2.3	4.6±1.1**	0.8±0.7	1.38±0.20	50.0±10.3**	26.1±4.2**	13.7±2.5**	10.5±6.9
P. Pudupatti (n=45)	12.9±3.0	0.81±0.34	8.9±2.9	5.1±2.2	0.8±0.3	1.5±1.0	1.54±0.40	5.5±1.4	1.3±4.8	0	4.2±1.4

Data source: Author's field survey (September and December, 2008)

Note: Numbers after "±" indicate standard error.

\* Indicates significant difference at 5% level.

\*\* Indicates significant difference at 1% level.



**Fig. 13** Relationship between Volume of Well Water and Income from Crops

Data source: Author's field survey (September, 2008)

Note: Colors painted over the markers indicate the range of standard water requirement:

□ < 500 mm    ■ 500–1,000 mm    ■ > 1,000 mm

Equation in the figure indicates the simple linear regression line.

relationship between the volume of well water consumed and the income from crop cultivation, and 2) crops which require more water could produce more value-added. Note that the volume of well water shown in the figure was much higher than the standard water requirement (See Table 4). This might be due to the loss of water when conveyed from the well to the field because most of the irrigation channels in the study area were not lined with concrete or other low-permeable materials. The figure simply shows the fact that “more water creates more money.” Such economic incentives for farmers accelerated the introduction and renovation of wells in the upper basin, as shown in Fig. 7 and Table 2.

Note here that electricity supply is essential for pumping groundwater from wells. Electricity for agricultural purposes is highly subsidized in Tamil Nadu. A flat rate system was introduced in 1984 (Rs.125/HP/year), but later electricity for agricultural purposes became totally free and remains so even now, except for a brief period in 2003, when a flat rate system was briefly re-introduced (Rs.250 /HP/year) [Palanisami *et al.* 2008]. Such highly subsidized electricity, along with the declining cost of



installation of wells, encouraged farmers to introduce or update wells.

## VII Discussion

India embarked on full-scale economic liberalization in 1991, and since then, the development of the industrial and service sectors has accelerated. Such a change in economic structure created an increased demand for cash crops, especially among urban populations, and spurred the agricultural transformation from food crops to cash crops in rural Tamil Nadu, including the study area. Since cash crops were usually grown in the dry season, they required additional irrigation water. Therefore, demand for the groundwater irrigation rapidly expanded. Several factors, including the decline in pumping machine prices, the cost of well drilling, and the existence of highly subsidized electricity [Kajisa *et al.* 2007; Palanisami *et al.* 2008], encouraged farmers to install private wells.

In the upper Gundar River Basin, introduction of and deepening of wells, represented by the conversion from dug wells to dug-cum-bore wells, accelerated from the end of the 1990s. Such a rapid expansion of wells enabled more farmers to secure groundwater, which enhanced the introduction of cash crops. Given the positive correlation observed between the volume of well water used and income from crop production, farmers with good access to groundwater could gain higher income than before. However, the introduction of cash crops did not occur uniformly within the basin, but was confined to the upper part. The crop choice in the middle and the lower basin therefore remained the same, mainly concentrated in subsistence food crops. In the lowermost part of the basin, much of the cultivable land was even abandoned and left fallow. This must be due to the disappointing performance of wells in the area. As a result, a significant gap in farm income was created between the upper and the lower part of the same river basin.

The performance of wells is highly affected by the surface water and cropping conditions close to the well [Palanisami and Easter 1991; Srivastava *et al.* 2009]. If water is properly stored in the tanks, sufficient groundwater recharge, not only the direct one from tank water spread areas but also from the tank command area, can be expected [Srivastava *et al.* 2009]. In Saptur Village, the share of area under paddy in *nañcai* did not drop below 60% during the last two decades (Fig. 11), whereas the same figure in P. Pudupatti Village was less than 20% in 2008 (Fig. 12). Such a difference in the crop choice between the two villages was created by the difference in tank performance, which might further result in the varying performance of wells. Therefore, as a whole, the difference in tank performance might be the major reason for the difference in the crop choice within the river basin.

As argued above, tanks have been functioning as an important source of groundwater recharge.

However, the performance of tanks has been declining mainly due to their inadequate operation and maintenance [Palanisami and Easter 1991; Palanisami and Balasubramanian 1998; Sakthivadivel *et al.* 2004; Sivasubramaniyan 2006]. The expansion of wells was regarded as one of the biggest reasons for its decline, because once farmers secured well water, they began to lose their interest and motivation for getting involved in tank management [Janakarajan 2003]. In recent years, a variety of efforts have been undertaken by the State Government of Tamil Nadu to improve the performance of tanks, but they were not always effective. Restoring the physical condition of tanks through rehabilitation is indispensable, but equally crucial is finding ways to keep the rehabilitated tanks in good condition [Sakthivadivel *et al.* 2004]. In this sense, to seek an appropriate institutional framework for promoting people's participation in tank management would be a more important issue for mitigating the income gap found within the river basin.

## VIII Conclusion

In this article, we investigated the effects of the expansion of private wells on rural livelihood (income) in a tank-intensive watershed in the upper Gundar Basin in southern Tamil Nadu, focusing mainly on the effects of wells on crop choice. Due to the high density of tanks in the study area, subsistence food crops such as paddy, millets and pulses were planted at least until the mid-1990s in the entire basin, including the two study villages. After the late-1990s, however, the construction/installation of wells accelerated, especially in the upper part of the basin. This enabled farmers to shift their crop choice from subsistence food crops to cash crops, because the latter requires more water. However, such a shift in crop choice did not occur in the lower part of the basin, which can be attributed to the disappointing performance of wells in the area. Because of the disappointing performance, farmers did not dare to try to install/update their wells. Finally, such a difference in the expansion of wells resulted in a significant income gap within the same river basin. For rural development in disadvantaged areas such as the lower part of the basin, various governmental support such as the National Rural Employment Guarantee Act (NREGA) may be essential.

## Acknowledgements

This article is one of the outcomes of the JSPS Global COE Program (E-04): "In Search of Sustainable Humansphere in Asia and Africa," and is financially supported by the Grant-in-Aid for Scientific Research Kiban C, No. 19580379: "Impact Assessment of Tank Modernization Project on Agricultural Water Use and Livelihood of the Farmers in Tamil Nadu, India." The authors acknowledge useful comments from and discussions with the referees, Prof. Koichi Fujita, Prof. Yasuyuki Kono, Prof. Kuppanan Palanisami, Dr. Muniandi Jegadeesan, and other post-doctoral colleagues

who participated in the *Tuesday Seminar* in the Center for Southeast Asian Studies, Kyoto University. We also gratefully thank to Mr. S. Subburaj for his kind support and assistance during our field survey.

## References

- Allen, R. G.; Pereira, L. S.; Raes, D.; and Smith, M. 1998. *Crop Evapotranspiration: Guideline for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56. Rome: FAO.
- Esho, H. 2008. *Ririku shita Indo Keizai: Kaihatsu no Kiseki to Tenbo* [Indian Economy has Taken Off: Track and Prospects of Development]. (in Japanese) Kyoto: Minerva Shobo.
- Ford Foundation and Anna University. 2001. *Participatory Rehabilitation and Management in Sowdarpatti Tank*. Chennai: Anna University.
- Fujita, K. 2011. Introduction: Socio-Economic Dynamics in Tank-Irrigated Rural Area in Contemporary Tamil Nadu, India. *Southeast Asian Studies* 49 (1): 3–21.
- Government of Tamil Nadu (GOTN). Various issues. *Season and Crop Report of Tamil Nadu*. Department of Economics and Statistics, Tamil Nadu, Chennai.
- . 2004. *Directory of Wholesale Agricultural Produce Assembling Markets in India*. Ministry of Agriculture.
- . 2006a. *Statistical Handbook of Tamil Nadu 2006*. Department of Economics and Statistics. Tamil Nadu.
- . 2006b. *Statistical Handbook of Sedapatti Block 2004–05*. Department of Economics and Statistics, Madurai District.
- . 2006c. *Sedapatti Block “G-Return” Data 2005–06*. (Unpublished) Department of Economics and Statistics, Madurai District.
- . 2006d. *Statistical Handbook of Tirumangalam Block 2004–05*. Department of Economics and Statistics, Madurai District.
- . 2006e. *Tirumangalam Block “G-Return” Data 2005–06*. (Unpublished) Department of Economics and Statistics, Madurai District.
- . 2006f. *Statistical Handbook of Kallikudi Block 2004–05*. Department of Economics and Statistics, Madurai District.
- . 2006g. *Kallikudi Block “G-Return” Data 2005–06*. (Unpublished) Department of Economics and Statistics, Madurai District.
- . 2006h. *Statistical Handbook of Kariapatti Block 2004–05*. Department of Economics and Statistics, Virudhunagar District.
- . 2006i. *Kariapatti Block “G-Return” Data 2005–06*. (Unpublished) Department of Economics and Statistics, Madurai District.
- . 2007a. *District Groundwater Brochure, Madurai District*. Central Ground Water Board, Ministry of Water Resources.
- . 2007b. *District Groundwater Brochure, Virudhunagar District*. Central Ground Water Board, Ministry of Water Resources.
- . 2008a. Environmental Status of Gundar Including Kottakudiar (Uthirakosamangaiar) and Vembar Basin. In *Micro Level Environmental Status Report*, edited by Public Works Department (PWD) of Tamil Nadu Government.
- . 2008b. *Fourth Census of Minor Irrigation Schemes (Saptur)*. Public Works Department (PWD) of Tamil Nadu Government.
- . 2009a. *Water Resources Atlas of Madurai District, Sedapatti Block*. District Rural Development Agency, Madurai.
- . 2009b. *Water Resources Atlas of Madurai District, Tirumangalam Block*. District Rural Development Agency, Madurai.
- . 2010. IAMWARM Project [Online]. Available at <http://www.iamwarm.gov.in/brief-project.asp> (verified October 12, 2010).
- Gowtham, B.; and Lawrence, J. F. 2010. Identification of Groundwater Flow Direction Using Tritium Analysis of

- Lower Gundar Basin, Southern Tamil Nadu, India. In *Recent Trends in Water Research: Hydrochemical and Hydrological Perspectives*, edited by S. Chidambaram, Al. Ramanathan, K. Shivanna, and J. R. Arthur, pp. 51–57.
- Janakarajan, S. 1993. Economic and Social Implications of Groundwater Irrigation: Some Evidence from South India. *Indian Journal of Agricultural Economy* 48: 65–75.
- . 2003. Need to Modernize the Tradition: Changing Role of Tanks in Response to Scarcity and Variability (draft version). In *Proceedings of the Conference on Market Development of Water and Water Technologies through Environmental Economics*, 30<sup>th</sup>–31<sup>st</sup> October 2003, Delhi.
- Kajisa, K.; and Palanichamy, N. V. 2006. Income Dynamics in Tamil Nadu, India from 1971 to 2003: Changing Roles of Land and Human Capital. *Agricultural Economics* 35: 437–448.
- Kajisa, K.; Palanisami, K.; and Sakurai, T. 2007. Effects on Poverty and Equity of the Decline in Collective Tank Irrigation Management in Tamil Nadu, India. *Agricultural Economics* 36: 347–362.
- Ludden, D. 1979. Patronage and Irrigation in Tamil Nadu: A Long-Term View. *Indian Economic and Social History Review* 16 (3): 347–365.
- Mahendra Dev, S.; Ravi, C.; Viswanathan, V.; Gulati, A.; and Ramachander, S. 2004. *Economic Liberalisation, Targeted Programmes and Household Food Security: A Case Study of India*. MTID Discussion Paper No.68. Washington, D.C.: International Food Policy Research Institute.
- Palanisami, K. 2000. *Tank Irrigation: Revival for the Prosperity*. New Delhi: Asian Publication Services.
- Palanisami, K.; and Balasubramanian, R. 1998. Common Property and Private Prosperity: Tanks vs. Private Wells in Tamil Nadu. *Indian Journal of Agricultural Economy* 53: 600–613.
- Palanisami, K.; and Easter, K. W. 1991. Hydro-Economic Interaction between Tank Storage and Groundwater Recharge. *Indian Journal of Agricultural Economy* 46: 174–179.
- Palanisami, K.; Jegadeesan, M.; Fujita, K.; and Kono, Y. 2008. *Impact of Tank Modernization Programme on Tank Performance in Tamil Nadu State, India*. Kyoto Working Papers on Area Studies No.5 (G-COE series No.3), Center for Southeast Asian Studies, Kyoto University.
- Palanisami, K.; Vidhyavathi, A.; and Ranganathan, C. R. 2008. Wells for Welfare or “Illfare”? Cost of Groundwater Depletion in Coimbatore, Tamil Nadu, India. *Water Policy* 10: 391–407.
- PSS Borewell Services. 2010. Website of PSS Borewell Services [Online]. Available at <http://www.pssborewell.com/> (verified October 27, 2010).
- Sakthivadivel, R.; Gomathinayagam, P.; and Shah, T. 2004. Rejuvenating Irrigation Tanks through Local Institution. *Economic and Political Weekly* 39(31): 3155–3164.
- Shah, A. 2000. Watershed Programmes: A Long Way to Go. *Economic and Political Weekly* 35(35): 3521–3526.
- Sivasubramanian, K. 2006. Sustainable Development of Small Water Bodies in Tamil Nadu. *Economic and Political Weekly* 41(26): 2854–2863.
- Sivasubramanian, K.; and Vaidyanathan, A. 2001. Tanks of Periyar Vaigai Basin. In *Tanks of South India*, edited by A. Vaidyanathan. New Delhi: Centre for Science and Environment.
- Srivastava, R. C.; Kannan, K.; Mohanty S.; Nanda, P.; Sahoo, N.; Mohanty, R. K.; and Das, M. 2009. Rainwater Management for Smallholder Irrigation and Its Impact on Crop Yields in Eastern India. *Water Resour. Manage* 23: 1237–1255.
- Vaidyanathan, A. 2006. Restructuring Watershed Development Programmes. *Economic and Political Weekly* 41(27): 2984–2987.

#### Appendix: Type of Wells

The definition of various types of wells is as follows (PSS Borewell Services [2010]; Fig. 8).

1. Dug well: A dug well is constructed by digging the soil or blasting the underground rock.
2. Bore well: A bore well is a well of 4 1/2” to 12” in diameter drilled into the earth for retrieving water. It is cased in the region of loose subsoil strata and opened in hard rock or in crystalline rock. High grade PVC pipes are used for casing in bore wells. The depth of a bore well can vary from 150 feet to 1,500 feet.
3. Dug-cum-bore well: A dug-cum-bore well is constructed by inserting a pipe from the bottom of a dug well vertically (sometimes horizontally) deeper underground to lift up groundwater either by an electric motor or a diesel engine.